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TITLE: A MIMO-OFDM PREAMBLE FOR CHANNEL ESTIMATION

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A MIMO-OFDM PREAMBLE FOR CHANNEL ESTIMATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Serial No. 60/470,832, filed on May 14, 2003 and entitled "A MIMO-OFDM PREAMBLE FOR CHANNEL ESTIMATION" (Attorney Docket No. MP0337PR).

BACKGROUND

[0002] Wireless phones, laptops, PDAs, base stations, and other systems may wirelessly transmit and receive data. A single-in-single-out (SISO) system may have two transceivers in which one predominantly transmits and the other predominantly receives. The transceivers may use multiple data rates and may select from these rates based on channel quality.

[0003] A multi-antenna system, such as an $M_R \times M_T$ multiple-in-multiple-out (MIMO) wireless system 100, such as that shown in Fig. 1, uses M_T transmit antennas 104 at a first transceiver 102 and M_R receive antennas 108 at a second transceiver 106. The first and second transceivers 102 and 106 in Fig. 1 are designated "transmitter" and "receiver", respectively, for the purposes of illustration, but both transceivers 102 and 106 may transmit and receive data.

[0004] The multiple antennas may enable the MIMO system to improve link quality (e.g., achieve a minimum bit error rate (BER)) and/or achieve high data rates. The MIMO system may improve link quality by using a transmission signaling scheme called "transmit diversity," where the same data stream is sent on multiple transmit antennas 104, creating redundancies that may be used by the receiver 106 to obtain an estimate of the received data. The MIMO system may achieve high data rates by using a transmission signaling scheme called "spatial multiplexing," where a data bit stream may be demultiplexed into parallel independent data streams. The independent data streams are sent on different transmit antennas 104 to obtain an increase in data rate corresponding to the number of transmit antennas 104 used. The MIMO system may use a combination of these two techniques to achieve at least some of the benefits of both techniques.

[0005] SISO and MIMO systems may use channel estimation techniques to determine the quality of the channel(s) over which data is being exchanged in the wireless system. The transmitter may transmit training sequences, which include symbols known to the receiver, for channel estimation. For a MIMO system, channels between all pairs of the transmit

(T_x) and receive antennas (R_x) should be estimated. This may require extra training overhead.

SUMMARY

[0006] A wireless system, such as an N X N MIMO-OFDM system may include a transceiver with N antennas and a transmit training module and a transceiver with N antennas and a receive training module. The transmit training module may generate a preamble structure including one or more training symbols. Each training symbol includes a number of data symbols, each data symbol corresponding to a particular tone. Each training symbol has a pattern in which data symbols and null symbols are transmitted on all tones and on all transmit antennas. The pattern for each training symbol corresponds to a cyclic shift of the patterns of the other training symbols.

[0007] The receive training module uses the received preamble to determine the gain at each antenna for each tone. In an embodiment, the receive training module may receive a preamble including only one training symbol and, for each antenna, interpolate the values for tones on which null symbols are transmitted from the data symbols received on that antenna. In another embodiment, the receive training module may receive a preamble including N training

symbols (one for each transmit antenna). When all training symbols are received, the receive training module will have received each data symbol on the corresponding tone from each of the antennas. For each antenna, the receive training module may determine the gain at each antenna for each tone by performing an inverse Fourier transform on the data symbols received on that antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is a block diagram of a wireless multiple-in-multiple-out (MIMO) communication system.

[0009] Figure 2 is a preamble structure for a single-in-single-out (SISO) communication system.

[0010] Figure 3 shows a preamble structure for a 3 X 3 MIMO system.

[0011] Figure 4 shows a training symbol structure for a first training symbol.

[0012] Figure 5 shows a training symbol structure for a second training symbol.

[0013] Figure 6 shows a training symbol structure for a third training symbol.

[0014] Figure 7A is flowchart describing a training operation at a transmitter.

[0015] Figure 7B is a flowchart describing a training operation at a receiver.

[0016] Figure 7C is a flowchart describing an alternative training operation at a receiver.

[0017] Figure 8 is an alternative preamble structure for a 3 X 3 MIMO system.

[0018] Figure 9 is an alternative training symbol structure.

DETAILED DESCRIPTION

[0019] Figure 1 illustrates a wireless multiple-in-multiple-out (MIMO) communication system 100, which includes a first transceiver 102 with M_T transmit (T_x) antennas 104 and a second transceiver 106 with M_R receive (R_x) antennas 108, forming an M_R X M_T MIMO system. For the description below, the first transceiver 102 is designated as a "transmitter" because the transceiver 102 predominantly transmits signals to the transceiver 106, which predominantly receives signals and is designated as a "receiver". Despite the designations, both "transmitter" 102 and "receiver" 106 may transmit and receive data.

[0020] The transmitter 102 and receiver 106 may be part of a MIMO-OFDM (Orthogonal Frequency Division Multiplexing) system. The IEEE 802.11a standard describes one type of

OFDM system and the protocols used by such a system. In an OFDM system, a data stream is split into multiple substreams, each of which is sent over a subcarrier frequency (also referred to as a "tone"). In an embodiment, the transmitter 102 and receiver 106 may be implemented in a WLAN (wireless Local Area Network). It is also contemplated that such transceivers may be implemented in other types of wireless communication devices or systems, such as mobile phones, laptops, personal digital assistants (PDAs), and base stations.

[0021] The antenna in the transmitter 102 and receiver 106 communicate over channels in a wireless medium. In Figure 1, **H** represents the reflections and multi-paths in the wireless medium, which may affect the quality of the channels.

[0022] In MIMO-OFDM systems, channel estimation may be used to estimate wireless channel gain and phase on each tone of the MIMO-OFDM system. Figure 2 shows a preamble structure 200 for an exemplary OFDM system, e.g., an IEEE 802.11a WLAN (Wireless LAN). The transmitter 102 transmits a cyclic prefix (CP) 202 followed by two identical training symbols 204 (designated "L1") to the receiver 106.

[0023] The training symbols 204 contain known data on each of the tones to aid in estimation at the receiver.

For example, in an IEEE 802.11a system, a BPSK (binary phase shift keying) signal is sent on each of the 52 tones (designated -26 to 26 with the DC (zero) tone omitted). The receiver uses the known values to estimate the medium characteristics on each of the frequency tones used for data transmission. There may be a frequency offset in the channel which may introduce interference among the various carriers in the OFDM signal. The training symbol L1 is repeated to aid in determining the fine frequency adjustment for such a frequency offset.

[0024] The preamble structure 200 shown in Figure 2 may be suitable where only one channel needs to be estimated, e.g., for a SISO system. However, in a MIMO system, channels between all pairs of transmit (T_x) and receiver (R_x) antennas should be estimated. Figure 3 shows a preamble structure 300 for a 3 X 3 MIMO system according to an embodiment. The preamble structure includes three training symbols, designated "L1" 302, "L2" 304, and "L3" 306 (one for each T_x-R_x antenna pair). Each of these training symbols may be repeated to aid in determining the fine frequency adjustment. Each training symbol pair may be preceded by a cyclic prefix. In an N X N MIMO system, the preamble structure may include N training symbols (L1, L2,…,LN).

[0025] In an embodiment, the training symbols L1, L2, L3 have a cyclic transmission pattern as shown in Figures 4, 5, and 6, respectively. The transmitter may include a T_x training module 120 (Figure 1) that generates training symbols and prepares the symbols for transmission. Referring to Figure 4, transmit antenna T_{x1} transmits eighteen "A" symbols (A1…A18). An A symbol is transmitted on every third tone, beginning at tone -26, and a null (zero) value on the intervening tones. Likewise, transmit antenna T_{x2} transmits seventeen "B" symbols (B1…B17) on every third tone, beginning at tone -25, and a null value on the intervening tones, and transmit antenna T_{x3} transmits seventeen "C" symbols (C1…C17) on every third tone, beginning at tone -24, and a null value on the intervening tones. To provide for even power distribution, each of the "A" symbols may have a magnitude of $\sqrt{\frac{52}{18}}$ (since they constitute eighteen of the fifty-two tones), and each of the "B" and "C" symbols may have a magnitude of $\sqrt{\frac{52}{17}}$ (since they each constitute seventeen of the fifty-two tones).

[0026] The receiver 106 may include an R_x training module 130 (Figure 1) that processes received training symbols. The receiver may receive the signals from all of the

transmit antennas and the R_x training module may divide out the corresponding symbol (A, B, or C) to determine the gain at the transmitting antenna for that tone. For example, when receiving symbol L1, the receiver may divide out symbol A1 for tone "-26" to determine the gain at T_{x1} for tone "-26".

[0027] As shown in Figures 5 and 6, the training symbols L2 and L3 have a similar transmission pattern, but with a cyclic shift between patterns, such that after all of the training symbols have been sent, the "A", "B", and "C" symbols sequences have been transmitted on all of the transmit (T_x) antennas. The receiver 106 may then use this information to determine the gain at each transmit antenna for each tone. For example, the receiver may combine all of the tones horizontally for each transmit antenna and then take an inverse Fourier transform (IFT) to get the actual time domain waveform that is sent through the respective antenna.

[0028] In this embodiment, all of the antennas are on simultaneously in the time domain, but only one is on the frequency domain for purposes of channel estimation. This may be done to simplify automatic gain control (AGC) requirements at the receiver 106. In this manner, every symbol period can have all transmit antennas transmitting

such that the received power does not vary substantially between L1, L2, and L3. Consequently, no adjustment of receiver AGC between training symbols may be necessary, and the AGC can be set before symbol L1 and held at a constant value for L2 and L3 and still provide an acceptable dynamic range at the receiver. This may be preferable to sending a preamble over each of the transmitters in turn (i.e., one antenna transmitting and the others not transmitting) because the dynamic range may change between antenna transmission periods. Furthermore, the embodiment described here avoids changing the transmit power for each antenna during preambles and during data symbols.

[0029] Figures 7A and 7B are flowcharts describing training operations performed at the transmitter 102 and receiver 106, respectively. The T_x training module 120 generates a preamble with N training symbols (block 702). The transmitter transmits the preamble on N transmit antennas (block 704). The transmitter transmits a first training symbol simultaneously on all N antennas (block 702). The transmitter then transmits the remaining N-1 training symbols in sequence (block 706), with each training symbol having a pattern shifted from that of the previously sent training symbol. The receiver receives the pattern-shifted training symbols such that each symbol

sequence (e.g., A1…A18, B1…B17, C1…C17) has been received from each of the transmit antennas 104 (block 708). The R_x training module 130 may then use this information to determine the gain at each transmit antenna for each tone (block 710).

[0030] For a given transmit power, this technique may provide a boost in training power for each subcarrier relative to data transmission, since only one antenna transmits on each subcarrier and in each training symbol. For a given training symbol, all available power can be reserved for a given data symbol for each tone, effectively increasing power by a factor of three (for a 3 X 3 MIMO) to estimate the channel. For example, in training symbol L1 (Figure 4), all available power can be reserved for symbol B1 in tone "-25".

[0031] The repetition of training symbols allows estimation of carrier frequency offsets and for additional processing gain for channel estimation. In many situations, the frequency offset will not change significantly between channels. In these situations, the training symbols after L1 (i.e., L2 and L3) may not be repeated, as shown in Figure 8, and the frequency offset may be determined from the repeated L1 training symbols.

[0032] The interleaved pattern shown in Figures 4-6 (i.e., with null symbols intervening the "A", "B", and "C" symbols) may be advantageous in mediums with low channel delay spreads. "Channel delay spread" refers to the spread in delays between different echoes, e.g., the dominant path (e.g., line-of-sight) and secondary paths. For example, for a channel with a line-of-sight transmission path, there may be few echoes. In this case, the channel response at each of the tones in the training symbol L1 at the receiver 106 may be similar.

[0033] As shown in Figure 7C, for channels the receiver determines to have a low delay spread (block 712), the receiver may indicate to the transmitter that only one training symbol is required (block 714). The receiver may receive the first training symbol (block 716), and the R_x training module 130 may perform a frequency domain interpolation (block 718), i.e., interpolate the zero values between adjacent "A", "B", and "C" symbols, to determine the gain at each antenna for each tone (block 720). In this case, the transmitter may send fewer training symbols, e.g., only L1, thereby reducing the training overhead.

[0034] In alternative embodiments, the transmission pattern may be modified by grouping the staggered symbols,

e.g., in groups, as shown in Figure 9. However, this training symbol structure may preclude the optional frequency domain interpolation described above in reference to Figure 7C.

[0035] Although IEEE 802.11 systems have been described, the techniques may be used in other OFDM system, such as IEEE 802.16 systems.

[0036] A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, blocks in the flowchart may be skipped or performed out of order and still produce desirable results. Accordingly, other embodiments are within the scope of the following claims.